Technical Report No. 3

[redacted]

25X1

a. Current Status of Work

The following areas have been worked on during the period starting February 26, 1965.

1. Target fabrication. As a first go around a target confirguration as shown in Fig. 1 was adopted. The ratio between the successive targets is $\sqrt[10]{10}$. The largest target is 1 line/mm. The range from 1 - 1000 lines/mm then falls naturally into three series: 1 - 10 lines/mm, 10 - 100 lines/mm, and 100 - 1000 lines/mm. Each series is broken down into the following steps.

Step	l/mm factor
1	1,000
2	1,259
3	1,585
4	1,996
5	2,512
6	3,163
7	3,982
8	5,014
9	6,313
10	7,948
11	10,000

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The first series was fabricated in the following way. First one step was drawn on a large scale. Then this was photographed. From this photograph all the steps of the first series were printed by varying the enlargement for each step. Then this series was rephotographed and the first series was obtained in negative form. This then was printed as a direct contact print.

The second series was accomplished by taking the negative of the first series and photographing it with a 10 to 1 reduction. The optics usedwas a Wild "YVAR" lens, f' = 13mm, f/1.9.

By photographing the positive of the first series in the same manner, we ended up with a negative of the second series.

As a third step, just to get an idea of the difficulties involved, we took a negative of the second series and reduced it ten times with the setup used to make the second series. The interesting part here was that we could resolve 500 lines/mm without any trouble.

The targets fabricated this way are very encouraging. For our purpose they are fine up to 500 lines/mm. We feel, however, that they should be improved so as to make the phase measurements possible. Therefore, the following steps are initiated.

a) Experiments are being made to determine various methods of developing the film. These methods were discussed by Dick, a representative of the customer, and Harold of our organization.

b) The contact print necessary to get a series one positive is being eliminated. The contact print will be made at the large stage where a loss of detail is much less critical. Furthermore, parallel illumination will be used in the printing process.

c) In order to hold precise reduction factors and locate the three series precisely on one piece of film, a more accurate setup is being constructed.

d) With more precise processing combined with a better lens, it will be attempted to go up to 1000 lines/mm.

2. During this period an experimental setup was fabricated to give us an idea of the precision obtainable in this method measuring the transfer function of the lens and also to find the best value of the contrast in the filters and the necessary frequency range in the filters. After the equipment was finished, the first measurements show that a contrast of 2% in the filters is too small. We therefore are now waiting for more filters with different contrasts.

After working with the instrument our overall impression is that it will be easy to use when all parameters are adjusted.

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3. Mathematical discussion of the attainable precision.

Introduction

Let us first, for the sake of simplicity, assume that the light distribution in the target is sinusoidal. We shall write for the intensity in the object plane:

$$I = I_o \left[1 - V_T \cos \omega x \right] \qquad (1)$$

in which V_T stands for the visibility of the target and ω is proportinal to its line frequency.

In the image plane this leads to an intensity distribution

$$I' = I'_o \left[1 - \tau V_T \cos (\omega x + \varphi) \right] \qquad (2)$$

in which τ is the modulus of the transfer function of the lens under test, and φ its phase shift.

The underlying idea of the method is to use a compensation method in determining the values of τ and φ. There are two fundementally different ways of doing this. The first method consists of projecting the image (2) onto a filter with a periodic transmission. The principle of this method is to arrange things such that the emerging light distribution is uniform when the proper setings are made. We shall call this method the multiplicative method.

The second method consists of adding to the image given by (2) a second light distribution, such that the resultant sum again shows no modulation. This method we shall call the additive method.

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a. The Multiplicative Method

An absorpition filter that transforms a sinusoidal intensity distribution exactly into a uniform intensity distribution must have a periodic transmission according to

$$T = \frac{C}{1 - V \cos \omega x} \tag{3}$$

The first thing to note is that this function is not sinusoidal. In fact we have:

$$T = \frac{C}{\sqrt{1 - V^2}} \left[1 + 2 \sum_{1}^{\infty} \left(\frac{V}{1 + \sqrt{1 - V^2}} \right)^n \cos n\omega x \right] \tag{4}$$

T can not exceed unity, hence C must not exceed 1 - V. So the average transmission cannot exceed $\sqrt{\dfrac{1 - V_o}{1 + V_o}}$.

Equation (4) in itself is not of great importance because we cannot expect to produce filters that are faithfully represented by it. It is, however, indicative of some of the problems associated with the multiplicative method. In multiplying two periodic functions the harmonics get "mixed." The simplest case is the generation of a second harmonic by multiplying two sinusoidal functions. A much more dangerous effect is the contribution to the first harmonic in the final image by the second harmonic in the object.

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For the moment we shall leave these matters aside.

We now consider a target image

$$I' = \left[I'_o \quad 1 - \tau V_T \cos(\omega x + \varphi) \right] , \tag{1}$$

and feed it through a filter with transmission

$$T = C \left[1 + V_o \cos(\omega x + \psi) \right] \tag{5}$$

We assume that the product $\tau V_T V$ can be neglected, and so find for the light distribution to be observed:

$$\begin{aligned} I'' &= CI'_o \left[1 - \tau V_T \cos(\omega x + \varphi) + V_o \cos(\omega x + \psi) \right] \\ &= CI'_o \Big[1 + (V_o \cos\psi - \tau V_T \cos\varphi) \cos\omega x \\ &\qquad - (V_o \sin\psi - \tau V_T \sin\varphi) \sin\omega x \Big] \end{aligned} \tag{6}$$

A uniform light distribution will be observed when

$$V_o = V_T \tag{7}$$

$$\psi = \varphi \tag{8}$$

The phase adjustment can be made by either varying φ (moving the target) or varying ψ (moving the filter). The contrast adjustment must be made by varying the contrast of the target V_T; it does not seem feasible to vary the filter contrast.

Assuming that the limiting visibility the eye can perceive is ε, Equation (6) leads to:

$$(V_o \cos\psi - \tau V_T \cos\varphi)^2 + (V_o \sin\psi - \tau V_T \sin\varphi)^2 < \varepsilon \quad (9)$$

This Equation can be solved geometrically in a polar coordinate diagram. The result is that we can expect the following measuring accuracies:

$$\Delta(\tau V_T) = \varepsilon \quad (10)$$

$$\Delta(\varphi - \psi) = \frac{\varepsilon}{V_o} \quad (11)$$

From Equation (10) we can find the accuracy in τ:

$$\Delta\tau = \frac{\varepsilon\tau}{V_o} \quad (12)$$

It follows that the relative accuracy in τ is constant. We observe, however, that as V_T can not exceed unity, the lowest value of τ that can be measured is equal to V_o.

b. The Additive Method

We add to the image of the target

$$I' = I'_o \left[1 - \tau V_T \cos(\omega x + \varphi)\right] \quad (2)$$

a second light distribution:

$$I'' = I'_1 \left[1 + V_o \cos(\omega x + \psi)\right] \quad (13)$$

The addition does not produce any higher harmonic problems. The intensity distribution to be observed is:

$$I' + I'' = I'_o \left[1 - \tau V_T \cos(\omega x = \varphi) \right] + I'_1 \left[1 + V_o \cos(\omega x + \gamma) \right]$$

$$= (I'_o + I'_1) + \left[I'_1 V_o \cos\gamma - I'_o \tau V_T \cos\varphi \right] \times \cos\omega x - \left[I'_1 V_o \sin\gamma - I'_o \tau V_T \sin\varphi \right] \times \sin\omega x \qquad (14)$$

A uniform light distribution is observed when

$$I'_1 V_o = I'_o \tau V_T \qquad (15)$$

$$\gamma = \varphi \qquad (16)$$

In this case we have two choices to make the contrast adjustment. We can vary either the reference beam contrast V_o, or the target contrast V_T.

1) We shall first assume that V_T is varied. Making the same assumption about the eye as in the previous section we have:

$$\tau = \frac{I'_1 V_o}{I'_o V_T} \qquad (17)$$

with

$$\Delta(I'_o \tau V_T) = (I'_o + I'_1)\,\varepsilon ,$$

or

$$\Delta\tau = \frac{I'_o + I'_1}{I'_1} \frac{\varepsilon\tau}{V_o} \qquad (18)$$

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For the phase error we find:

$$\Delta(\varphi - \psi) = \frac{I'_o + I'_1}{I'_1} \frac{\varepsilon}{V_o} \tag{19}$$

The lowest τ that can be measured is $\frac{I'_1}{I'_o} V_o$.

We see that the accuracies are worse than for the multiplication method. (Writing τ_L for the lowest value of τ that can be measured we have:

$$\Delta\tau = \frac{I'_o + I'_1}{I'_o} \varepsilon \frac{\tau}{\tau_L} \tag{20}$$

This shows that it is profitable to make the target beam brighter than the reference beam, and at the same time choose V_o quite high. The best we can do is to make V_o equal to unity. Then

$$\frac{I'_1}{I'_o} = \tau_L \tag{21}$$

and

$$\frac{\Delta\tau}{\tau} = \frac{1 + \tau_L}{\tau_L} \tag{22}$$

For the phase accuracy we find in this case:

$$\Delta(\varphi - \psi) = \frac{1 + \tau_L}{\tau_L} \varepsilon \tag{23}$$

So in this optimum case the difference between the additive and the multiplicative method is only a factor $1 + \tau_L$, a rather minor difference.

2) So far we assumed that the target contrast was varied and that the reference beam contrast was constant. We can, however, also vary the contrast of the reference beam, and leave the target contrast constant. In that case we have again

$$\tau = \frac{I'_1 \times V_o}{I'_o \times V_T} \qquad (24)$$

but now we have:

$$\Delta\left(I'_1 V_o\right) = \left(I'_o + I'_1\right)\varepsilon \qquad (25)$$

which leads to:

$$\Delta\tau = \frac{I'_o + I'_1}{I'_o V_T}\varepsilon \qquad (26)$$

This time it is possible to run into cases where very high values of τ cannot be measured. V_o can not exceed unity; consequently, the upper limit on τ is given by:

$$\tau_u = \frac{I'_1}{I'_o}\frac{1}{V_T} \qquad (27)$$

For the phase accuracy we find:

$$\Delta(\varphi - \psi) = \frac{I'_o + I'_1}{I'_o}\frac{\varepsilon}{\tau V_T} \qquad (28)$$

It is indicated to choose V_T equal to unity. Equation (26) shows that I'_o should be as large as possible compared to I'_1. If, however, we wish to measure out to $\tau = 1$, the best we can do is to make I'_o and I'_1 equal.

Summary:

	Multiplicative	Additive	
		Var. Targt.	Var. Ref.*
Filter contrast	τ_i	N.A.	N.A.
Target contrast	Variable	Variable	1
Reference beam contrast	N.A.	1	Variable
Reference beam int./ Target beam int.	N.A.	τ_L	τ_u
Accuracy in τ	$\frac{\tau}{\tau_L}\varepsilon$	$(1+\tau_L)\frac{\varepsilon\tau}{\tau_L}$	$(1+\tau_u)\varepsilon$
Accuracy in the phase (radians)	$\frac{\varepsilon}{\tau_L}$	$(1+\tau_L)\frac{\varepsilon}{\tau_L}$	$(1+\tau_u)\frac{\varepsilon}{\tau}$
Lower limit on τ	τ_L	τ_L	0
Upper limit on	1	1	τ_u

* τ_u will usually be chosen equal to one. Little is gained by giving up the high τ values.

4. Discussion of Best Setup for Viewer Test Equipment

In all our discussions about the actual configuration there was one recurring problem. The available space for the target in viewers is usually limited to space for a piece of film. Any variable contrast target will need more space than this, no matter how far we miniturize the target under the scheme outlined in our proposal.

In Section 3, however, we analysed another scheme in comparison to the proposed one. The additive system has many advantages in the case of testing viewers, since only a piece of film has to be inserted in the viewer to make the measurements.

In Fig. 2 we show a schematic outline of the additive scheme. Section A of this figure shows the viewer under test. In the film plane we insert a target with visibility 1. This target is imaged in the image plane of the viewer. The visibility of this image is modified by the τ of the viewer. We then look at this image with a microscope. Esentially, we mix this image (with the aid of a half-silvered mirror) with the image of an auxiliary target. There has to be provisions to change magnification in a limited range in this auxiliary path. Furthermore, there has to be a provision to adjust the two images phase-wise. This setup has advantages other than the fact that only a piece of film has to be inserted in the viewing equipment. The visibility of the image formed by the viewer is compared to the visibility of the auxiliary target. The optics in both beams viewing these two images are the same except for the zoom system.

Therefore the transfer coefficient for both beams is the same, provided we use matched objectives. (The maximum zoom range is only $\sqrt[10]{10}$ or 1.26.)

No problems are created by the higher harmonics being generated. The illumination of the target in the auxiliary beam is being studied further.

5. The measurement of the phase of the transfer function can be made by using an identical tartet in the image phane of the microscope. (In our present setup the filter is located in this plane.)

   Experiments with this setup will be conducted in the near future.

b. Problem Areas Encountered

No problem areas were encountered.

c. Projected Work for Next Monthly Period

When the filters are received, a full investigation of the best filter will be made combined with finding the precision of which the equipment is capable. The measurement of phase will be experimentally persued. The fabrication of the targets will be continued.

d. Status of Funds Expended

From the period of February 1, 1965 to April 23, 1965 the sum of $17,111.12 was spent on subject contract. This figure includes direct labor, materials, overhead and G. and A., and fixed fee.

e. <u>Documentation of any verbal committments and/or agreements with the Technical Representatives of the Contracting Officer during the reporting period</u>

There have been verbal discussions during this period relative to the fabrication of the filters. As soon as the camera in our customer's laboratory is in working order, we are promised a set of experimental filters.

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Submitted by

Enclosure: Figures 1,2

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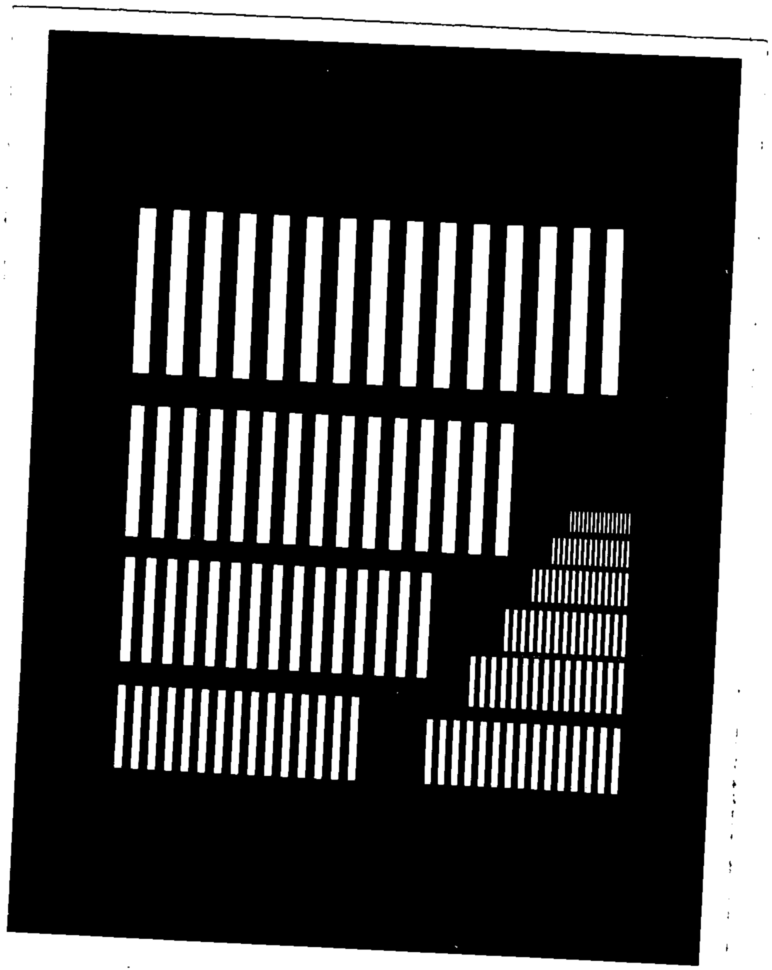

Fig. 1

Schematic of modified Sine-Wave Tester

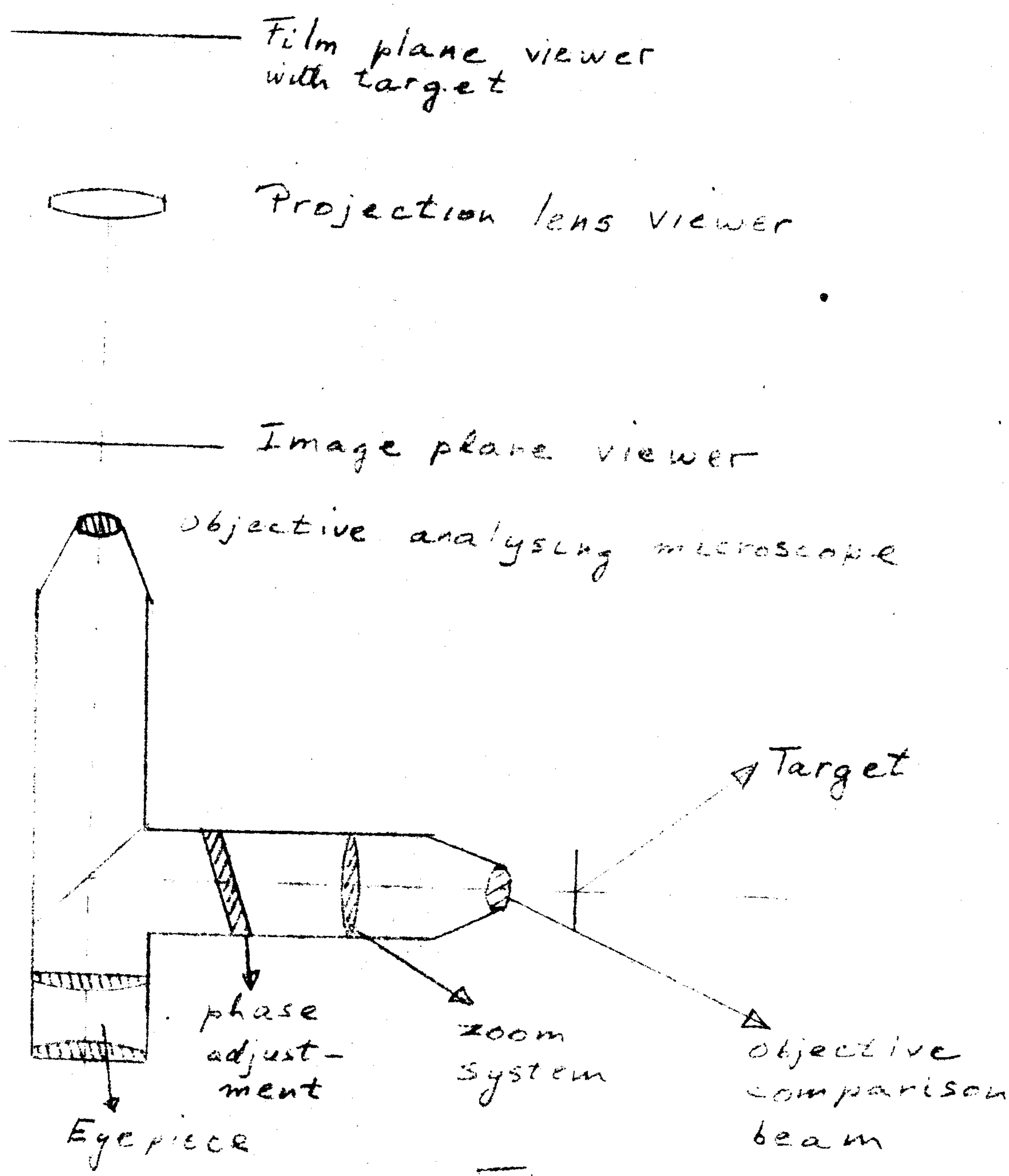

Figure 2

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